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Tunnel magnetoresistance in magnetic tunnel junctions with embedded nanoparticles

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Abstract

© 2015 IEEE. We present a theoretical simulation to calculate the tunnel magnetoresistance (TMR) in magnetic tunnel junction with embedded nano-particles (npMTJ). The simulation is done in the range of coherent electron tunneling model through the insulating layer with embedded magnetic and non-magnetic nano-particles (NPs). We consider two conduction channels in parallel within one MTJ cell, in which one is through double barriers with NP (path I in Fig. 1) and another is through a single barrier (path II). The model allows us to reproduce the TMR dependencies at low temperatures of the experimental results for npMTJs [2-4] having in-plane magnetic anisotropy. In our model we can reproduce the anomalous bias-dependence of TMR and enhanced TMR with magnetic and non-magnetic NPs. We found that the electron transport through NPs is similar to coherent one for double barrier magnetic tunnel junction (DMTJ) [1]; therefore, we take into account all transmitting electron trajectories and the spin-dependent momentum conservation law in a similar way as for DMTJs. The formula of the conductance for parallel (P) and anti-parallel (AP) magnetic configurations is presented as following: $Gs^{P(AP)}$ = G0σk F, s^2/4π ∫ Cos (θs) $Ds^{P(AP)}$ Sin(θ)dθsd, where Cos(θs) is cosine of incidence angle of the electron trajectory θs, with spin index s=(↑,↓), kF, s, is the Fermi wave-vector of the top (bottom) ferromagnetic layers; for simplicity the top and bottom ferromagnetic layers are taken as symmetric; $G0=2e^2/h$ and σ is area of the tunneling cell. The transmission probability $Ds^{P(AP)}$ depends on diameter of NP (d), effective mass m and wave-vector of the electron kNP attributing to the quantum state on NP (corresponding to the k-vector of the middle layer in DMTJs [1], and which is affected by applied bias V). Furthermore $Ds^{P(AP)}$) depends on Cos(θs), kF, s, barriers heights U1,2 and widths L1,2, respectively. The exact quantum mechanical solution for symmetric DMTJ was found in Ref.[1]. Here we employ parallel circuit connection of the tunneling unit cells, where each cell contains one NP with the average d less than 3 nm per unit cell's area (σ =20 nm^2), while tunnel junction itself has surface area S and consists of N cells (N=S/σ). The total conductance of the junction is G = Nx (G1↑+G2↑+G1↓+G2↓), where G1, s is dominant conductance with the NP (path I), G2, s is conductance of the direct tunneling through the single barrier (path II), and TMR=(G^P-G^{AP})/G^{AP} ×100%.

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